Tropical Cyclone tracks in present and future climates

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Due to the large social and economic impacts of tropical cyclones, it is fundamental to understand possible changes in tropical cyclone activity due to climate change. In this project we will focus on how tropical cyclone tracks could be influenced by climate change, especially due to the most robust projected changes in the tropical circulation. Tropical cyclone tracks strongly influence many tropical cyclone properties - including intensity and landfall frequency and location - which are of great importance to local populations. We will study changes in tropical cyclone tracks due to both natural variability and anthropogenically forced trends. As part of our analysis we will apply a cluster technique that we have previously applied to observed tropical cyclone tracks in different regions of the world, and that has given important insights on the different properties of tracks in different cluster types: e.g. seasonality, genesis location, intensity, landfalling rates and locations.

Our first approach will be to examine tracks of tropical cyclones in global and regional climate models under present and future climate scenarios. We will apply the same cluster technique to identify tropical cyclone track changes in future climate scenarios and the large-scale circulation associated with those changes. The analysis will be performed using output from many models, to assess the robustness of these track changes as well as the relevant dynamics.

The second approach is to examine synthetic tropical cyclone tracks generated by a statisticaldynamical as well as a purely statistical approach. These tracks will be associated with current and future climate scenarios. We will then compare the cluster analysis of synthetic tracks to that of the dynamical models' tracks. By using two distinct approaches, we will be able to make a detailed assessment of the robustness of the possible track changes in future climate. The longterm objective of this project is to build a scientific foundation for future projections of tropical cyclone landfall change associated with climate change.

Project Title: Central U.S. abnormality in climate change and its response to global warming
Institution: Saint Louis University
Principle Investigator: Zaitao Pan (PI) and Timothy Eicher (Co-PI)

Abstract

The climate system is complex and involves many intertwined, interactive processes. Consequently, the direction and magnitude of climate change is a result of the various positive and negative feedbacks. On a regional scale, local climate change also reflects remote forcing and teleconnection patterns. Diagnosing individual climate change feedbacks will improve the understanding of climate dynamics and shed light on separating climate change into natural and anthropogenic components. This project proposes feedback processes and examines their contribution to abnormal climate change in the central and eastern U.S., which experienced a cooling trend is past decades.

The first process to be examined is baroclinicity, where the horizontal gradient in surface warming increases thermal wind and baroclinic instability, which then further interacts with climate change. The second process is soil moisture feedback. Climate change causes soil moisture to change, which alters the soil heat capacity and thus causes a feedback on nearsurface temperature changes. The last process is the planetary boundary-layer (PBL) depth/lowlevel jet (LLJ) feedbacks. A stronger surface warming and thus a higher PBL height upstream produce a stronger nocturnal LLJ and moisture transport downstream, generating an increase in cloudiness leading to a subsequent cooling.

Given the processes outlined above, the objectives of our proposal are: 1) to determine to what extent the above regional feedbacks contribute to the unusual summer cooling in the central and eastern U.S.; 2) to assess if these feedbacks can help explain why most IPCC AR4 GCMs were unable to reproduce the cooling trends in their 20th century historic simulations; 3) to project if this cooling trend will continue in coming decades; and 4) examine if these feedback processes also contribute to similar local cooling documented over other continents. Address these issues will help determine whether the abnormal central and eastern U.S. climate change is a regional response to (i.e., a result of) global warming, suggesting that the cooling trend would continue in lock-step with global warming, or it is related to some other transient processes, meaning that the central and eastern U.S. would be much warmer if these processes disappear in the future.

To achieve our objectives, a series of numerical experiments will be carried out using the global NCAR Weather Research and Forecast (WRF) model and Climate WRF (CWRF) with enhanced land surface and boundary layer schemes. Statistical tools including canonical correlation analysis (CCA), principle component analysis (PCA), and factor separation will also be used to diagnose the associations between these feedbacks and anomalous mid-continent cooling.

Title: Quantification and reduction of uncertainties in projections of climate impacts on drought and agriculture for North America
PI and institution: Justin Sheffield, Princeton University.
Co-PI and institution: David Lobell, Stanford University.

Introduction to the Problem: Agricultural productivity is highly dependent on climate variability and is thus susceptible to future changes including temperature extremes and drought. The latter is expected to increase in frequency regionally over this century. However, the uncertainty in projections of drought and its impacts on agriculture is high due to emission scenarios, climate model differences, uncertainty in initial/boundary conditions, and translation to regional scales.
Climate models are unanimous in projecting future warming but differ in the magnitude and even sign of regional precipitation changes. They also differ in terms of extremes of temperature, precipitation and other meteorology. When projecting future impacts on crop productivity, these uncertainties are compounded because current crop models often use simplified treatments of climate response and do not include comprehensive treatments of water availability. Therefore, projections of regional climate change, variability and its impacts on water availability and agriculture are highly uncertain and reduction of uncertainties requires attention to all levels in the climate-water-agriculture continuum.

Rationale: Given the uncertainties in future agricultural production and the complex relationships between climate, hydrology and crop development, there is pressing need to make improved estimates of future changes in climate change and crop yields. ***We propose to evaluate the uncertainties in estimates of future changes in climate, water availability and agricultural production, and make improved estimates by incorporating state of the art knowledge of the relationships between climate, hydrology and agriculture into modeling and downscaling.***
This has ramifications for disaster preparedness and mitigation, policy making and the political response to climate change, and intersects with fundamental science questions about climate change, extremes and hydrologic cycle intensification. It is central to the mission of the Climate Program Office's MAPP program to "enhance the Nation's capability to predict variability and changes of the Earth's System" and directly addresses its priorities to evaluate and reduce uncertainties in climate projections. This work will leverage from the PIs' experience and ongoing activities in large-scale climate analysis and hydrologic modeling, particularly in changes in drought historically and under future climates, and agricultural modeling and relationships between climate and crop productivity.

Summary of work to be completed: 1. Quantify the relationships between hydroclimate variables and the implications for water, drought and agriculture based on observational data. 2. Evaluate sensitivities of hydrologic and crop models to changes in climate and drought. Differences in climate variability, land-atmosphere coupling and hydrologic persistence will lead to differences in key metrics of water and agriculture which will form the basis for evaluation of the uncertainties in future projections. 3. Evaluate current climate models in how they replicate these observed relationships using the CMIP5 long-term and decadal predictions. 4. Estimate uncertainties in future projections of climate, drought and agriculture using a cascade of climate, downscaling, hydrologic and crop models with strategic sampling to decompose sources of uncertainty. 5. Implement a set of methods to reduce uncertainties in future projections based on observational constraints including merging of climate model predictions, bias correction and scaling of climate model output, and improvements to impact models.

Observational constraints, diagnosis and physical pathways for precipitation and extreme event processes in next-generation global climate models

University of California, Los Angeles
J. David Neelin, Principal Investigator

Abstract

As climate models move to finer resolution, they can be evaluated against observations using new metrics. We propose to use and extend a set of measures developed from observations, on the scales that high-resolution global climate models are now reaching, to evaluate a targeted set of processes in current climate models. These will be evaluated for a set of models across a range of resolutions, including the higher resolutionmodels fromthe CoupledModel Intercomparison Project 5 (CMIP 5), and various higher-resolution models from specific modeling groups. An example of a moderately high resolution model (Community Atmosphere Model at 0.5 degree resolution) is used to show that a model with parameterized convection can qualitatively capture several aspects of the categories below, but there is considerable sensitivity to ill-constrained factors such as entrainment.

The analysis will provide assessment of model suitability for evaluation of changes in these statistics under climate change and provide feedback for model development, drawing on tools developed under previous NOAA funding. Specifically, we focus on four categories of related features of precipitation, water vapor and temperature characteristics, on a set of statistics to quantify these, and on the underlying mechanisms producing these features.

1. Onset of deep convection, its water vapor-temperature dependence, and relation to entrainment assumptions. A set of convective onset statistics from remote sensing and in situ data provide a quantification of recent developments on the dependence of convection on water vapor in the lower free troposphere. There are several indications from other groups and from NOAA-supported prior work, of a strong sensitivity of climate models to errors in this process.
2. Excursions to high water vapor and strong precipitation regime. Prior work has provided evidence of long tails in the probability distribution (PDF) of water vapor, with a Gaussian core surrounded by approximately exponential tails, characteristic of an advection interacting with a forcing that maintains a gradient. Such tails imply much more frequent excursions into the high-water vapor regime associated with intense precipitation than would occur with Gaussian statistics.
3. Quantification of similar long-tail behavior for surface temperature PDFs, seen in preliminary work in many locations. The presence of such tails implies a rate of increase of extreme events under a shift of the distribution under global warming very different from that of a Gaussian.
4. Interactions at the margins of convective zones: the inflow air mass transported into a convective region is modified along its trajectory until conditions for convective onset are reached. If the onset condition evaluated in 1 is incorrect, the margins of the convection zones can have errors of hundreds of kilometers, creating large errors at the regional scale. Under global change, differences among model representations of this condition can yield large differences in the predicted regional change.

Coordinated with a proposal from Rutgers University, diagnostics from internal variability will help constrain models in this category, and the role of these mechanisms will be evaluated for regional climate change in the models.

Towards improving convection parameterization and the MJO in next-generation climate models

PIs: Stefan Tulich (Lead; CIRES, University of Colorado and NOAA ESRL)
Julio Bacmeister (NCAR CGD)
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Abstract of Proposal

Tropical biases remain a significant problem in global atmosphere models, even at horizontal resolutions of 20-50 km. In addition to mean state errors, another glaring deficiency is the general absence of the 30-60-day Madden-Julian oscillation (MJO), which modulates the frequency of tropical cyclone genesis over several basins and interacts with the lower-frequency El-Nino Southern-Oscillation. It is thought that such errors stem mainly from deficiencies in convection parameterization, but the precise nature of these deficiencies remains unclear. In order to address such tropical problems, we propose to run and analyze a suite of short-term [O(10-day)], high-resolution weather hindcasts, focusing on a 40-day period of enhanced MJO activity during the Year of Tropical Convection (YoTC) when special observational and assimilated datasets are available. The hindcasts will be performed using 4 different high-resolution atmospheric models (GEOS-5, CAM5, HiRAM, and WRF) as part of a multi-institutional collaborative research effort. The goal is to see how simulations of the MJO and other high-impact weather phenomena, as well as the mean state, are affected by either i) increases in model resolution (going from 50- down to 5-km horizontal grid spacing) or ii) the use of a "superparameterization" of convection at 50-km horizontal grid spacing. Hindcasts will also be generated with each of the models' convection schemes turned off, to see how the various schemes tend to improve (or degrade) their respective model's performance at high resolution. We hypothesize that models with more realistic convective processes will do better at simulating the MJO, so our diagnosis of model output will include both process-level and global-scale aspects, and will compare these in order to test this hypothesis. Improved understanding of this convective process-global performance relationship will serve the overall goal of improved ability to simulate convection variability and the MJO in models used to predict changes in regional-scale climate and high-impact weather for the decades to come.

Understanding the Emerging Central-Pacific ENSO and Its Impacts on North American Climate

Principal Investigator: Prof. Jin-Yi Yu, UC Irvine

ABSTRACT

It is being increasingly recognized that there are two distinct types of El Niño-Southern Oscillation (ENSO): an Eastern-Pacific (EP) type that has its sea surface temperature (SST) anomalies centered near the South America coast and a Central-Pacific (CP) type that has its SST anomalies centered near the international dateline. IPCC AR4 simulations project that the CP type may become the prevailing type of ENSO in a future warmer world, which is consistent with the fact that CP ENSO events have occurred more frequently in the past three decades than in earlier decades. There is a need to better prepare for the emergence of this mode of tropical climate variability, and to revise existing modeling and prediction strategies developed primarily with the conventional EP type of ENSO in mind. One source of uncertainty in the prediction and projection of North American climate may have to do with whether or not modern climate models can produce both types of ENSO, simulate the alternation between them, and capture their different impacts. This project proposes data analyses and model experiments to better understand the evolution of the CP ENSO and its regional impacts on the Pacific-North America sector and to identify the key atmospheric and oceanic processes for differing the impacts of the CP and EP ENSO's on North American climate.

Specifically, this project will make use of the existing Coupled Model Intercomparison Project Phase 3 (CMIP3) simulations and the upcoming CMIP5 simulations to understand the relative importance of the extratropical forcing and tropical coupling in controlling the evolution of the CP ENSO and to identify the concurrent and extended impacts of CP and EP ENSOs on North American Climate. The different impacts produced by the EP and CP ENSOs will be translated into uncertainties in the prediction and projection of the North American climate variability and will be assessed. Partial-coupling and forced experiments will then be conducted to further understand how the ocean and atmosphere in the Pacific-North American sector respond to CP and EP ENSO forcing, how the responses are projected onto the Pacific-North American (PNA) and North Pacific Oscillation (NPO) modes of variability, and how they are manifested as variations in the Aleutian Low, Subtropical High, and tropospheric jestreams. Special attention will be given to understanding the ENSO-induced SST anomalies in the North Pacific, which are hypothesized to extend ENSO's influence on North America after the demise of the ENSO events. The possibility of using statistical models, such as the Markov model, to perform CP ENSO predictions using both extratropical and tropical information will also be explored.

This project is expected to quantify the sensitivity of North American climate to the alternation of the ENSO type and to make suggestions on how it can be better captured in modern climate models by laying out the specific atmospheric, oceanic, and coupled processes that establish the sensitivity. New metrics that gauge not only tropical but also extratropical atmospheric and ocean fields will also be developed to help further improve model simulations of the two types of ENSO. These efforts are relevant to (a) "support the development of next-generation global climate models" and (b) "evaluate uncertainties in regional-scale climate predictions and projections", both of which are priority areas specified by the FY2011 MAPP program for the research theme of *Advance in Regional-Scale Climate Predictions and Projections*.

Prediction, Validation, and Calibration of Coastal Storms and Associated High Impact Weather in Ensemble Regional Climate Simulations over the Northeast U.S.

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ABSTRACT

Increases in extreme weather events (heavy precipitation, strong winds, storm surge, etc…) under anthropogenic climate change would have profound consequences for both human society and the natural environment. The Northeast U.S. is particularly vulnerable, since there are frequent coastal storms in this populated region. The ability of atmosphere–ocean general circulation models (AOGCMs) to accurately simulate high impact weather and its trend is of great importance, but unfortunately these AOGCMs can not resolve many of the mesoscale features that cause damaging winds, heavy precipitation, and coastal flooding. A common approach has been to downscale these AOGCMs with regional climate models (RCMs) to better resolve these storms and the underlying surface characteristics; however, past RCM resolutions have been marginal (30-50-km) and few studies have explored the uncertainty of these predictions using ensembles. Furthermore, these raw ensembles are often biased or underdispersed, so more work is needed to calibrate them, especially for high impact weather events.

This project investigates the future changes (up to year 2070) of high impact weather over the Northeast U.S. using an ensemble of Weather Research and Forecasting (WRF) members at 20-km grid spacing nested within an ensemble of climate model simulations using the NCAR Community Climate System Model (CCSM). The first goal is to determine how well this joint ensemble system can predict previous extratropical cyclones and associated high impact weather over the western Atlantic and eastern U.S. during the cool seasons of 1981-2009. The CCSM and WRF members will use different physics perturbations and parameterizations to diversify a 15-member CCSM-WRF ensemble. An important science question is the role of sea surface temperature (SST) gradients in these predictions, so both high and coarse resolution SST will be used. Also, the upscale impact of diabatic heating from the storms will be explored using a new two-way nesting setup of CCSM-WRF being developed at Stony Brook University. The past predictions of cyclone strength, winds, precipitation will be bias corrected using observations and reanalyses and calibrated using an ensemble weighting scheme. The second goal of the project is to use the calibrated ensemble and future simulations to project changes in the statistics of high impact weather (cyclone tracks, heavy precipitation, storm surge, etc…) in the years 2040-2070. The future predictions will use a 14-member CCSM-WRF ensemble with two different emission scenarios and physics (WRF starting at 2040). A new approach to obtain high resolution SSTs in the future via downscaling the CCSM SSTs will be tested. The results will be compared with the NARCCAP ensemble results over the Northeast U.S.

Overall, this project is one of the first to apply high-resolution regional climate ensembles that are calibrated for future predictions of high impact weather. Thus, it will serve as a useful data source for decision makers interested in how heavy precipitation, storm surge, strong winds, and cold air outbreaks may change over the Northeast U.S. during the next several decades.

In-depth Regional Process-level Analyses of NARCCAP and AR5 simulations over North America: Towards Establishing Differential Credibility of Regional Climate Projections

Anji Seth, Principal Investigator, University of Connecticut
Linda O. Mearns, Principal Investigator, NCAR
Melissa Bukovsky and David Gochis, Co-Investigators, NCAR

Abstract

The proposed research will take an alternative approach to differential evaluation of model credibility by focusing on process-level evaluation rather than on simple metrics. We hypothesize that a consistent set of process-oriented model analyses can be developed and applied in different climate regimes, and that this suite of model analyses will help define credible model members whose future simulated climates will have value for regional climate change assessment. We are focusing on three regions in North America (Southwest, Great Plains, Northeast) with the following objectives: (1) Establish a framework for determining the differential credibility of climate simulations using a process-based methodology for three specified regions; (2) Develop process-level time-series analysis to follow identified mechanistic errors in the evolution (from current period into the future) of warm season precipitation in the regions; (3) Based on the process-level analysis, differentiate the credibility of the models using collective expert evaluation (CEE); (4) Translate the process-level information into quantitative metrics; (5) Compare these metrics with the baseline metrics of ENSEMBLES; (6) Compare credibility rankings based on our process-level collective expert evaluation and developed metrics with rankings based on the ENSEMBLES metrics and diagnose causes of differences. (7) Apply the developed framework to Coupled Model Intercomparison Project (CMIP5) high-resolution decadal predictions.

This research will employ simulation data sets produced through the North American Regional Climate Change Program (NARCCAP) and the global coupled model (50 km) decadal predictions in progress as part of CMIP5 for the present day and near future periods. The process-level investigations will first be conducted for the coupled global models (AOGCMs), atmospheric global models (time-slices), and the regional climate models (RCMs) involved in NARCCAP. Time series of process-level errors will be examined in the reanalysis-driven and AOGCM-driven present day simulations and followed into the future simulations. The importance of the errors as the models respond to the new forcing in the future will be evaluated. In this way, our analysis will focus on the effect of the more consequential errors on the model future response. Our purpose is to perform qualitative process-level collective expert evaluations for each region, which may then be transformed into quantitative indicators.

The ultimate goal of this analysis is to provide meaningful differential weighting of the models using a process-level approach that results in more robust estimates of future climate change. The process-level analyses have value in that, by enhancing our understanding of the evolution of processes under greenhouse gas forcing, uncertainties may be reduced in the sense that better understanding of important mechanisms at work will result. The proposed research directly addresses MAPP FY2011 Priority 1b: 'to evaluate uncertainties in the longterm prediction and projection of twenty-first century climate over North America leveraging NARCCAP and new CMIP5 projections'.

Nonlinearity of the Tropical Convection and the Asymmetry of the El Niño Southern Oscillation

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Co-PI: De-Zheng Sun
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Abstract

The asymmetry of ENSO is a measure of its nonlinearity, and may be a key ingredient in climate variability on the decadal and longer time-scales, particularly for the Pacific sector. Understanding its causes and ensuring accurate simulation of it by climate models is a key issue facing climate modelers who strive to make reliable forecast/projections of climate changes over the coming decades.

The proposed research attempts to address this issue by analyzing existing model runs as well as through conducting specially designed experiments. Our working hypothesis— is that the nonlinearity in deep convection is an important cause of the asymmetry in ENSO. Specifically, an increase of the nonlinearity of tropical convection will lead to an increase in the asymmetry of zonal wind stress and therefore an increase in the asymmetry of subsurface signal, favoring an increase of ENSO asymmetry.

We plan to analyze the coupled runs as well as the corresponding AMIP runs from the latest NCAR and GFDL models, including the diagnosis of the NCAR model runs with different convection schemes and with different model resolutions and the GFDL model runs with different convection schemes. We not only examine ENSO asymmetry in the surface fields such as SST, surface heat flux, and precipitation but also its subsurface manifestation. To understand how the changed wind stress associated with changed convection scheme will affect the subsurface asymmetry and thereby the SST asymmetry, we will perform forced experiments with the NCAR Pacific basin model, the POP global ocean models (the ocean component of CCSM4/CESM1) and the MOM4 (the ocean component of the GFDL coupled model) using the winds from the AMIP runs of NCAR and GFDL models. We will compare the results from the forced runs driven by observed winds. In addition, the forced runs will be perturbed by warm anomaly, cold anomaly, and the residual of wind stress from observations and model simulations. Experiments especially designed to understand the relative importance of the nonlinearity from the atmosphere and the nonlinearity from the ocean dynamics will also be conducted.

To further validate the effect of changes in convection schemes and model resolutions on the simulation of ENSO asymmetry we will find from NCAR and GFDL models, we also plan to examine the coupled runs as well as the corresponding AMIP runs from the ongoing IPCC AR5 data sets.

The purpose of proposed research is to provide a better understanding of how the simulation of ENSO—the asymmetry between its two phases in particular—in global climate models is affected by increases in model resolution and changes in convection scheme, in support of the development of next-generation climate models involving both higher resolution and improved physical representations.

Title: Development of an Adaptive Vertical Grid Scheme for Large Scale Models

Institution: Joint Institute for Study of the Atmosphere and Ocean, University of Washington
Investigator: Dr. Roger Marchand

Abstract –

In recent years the combination of increasing computational capability and uncertainties in climate simulations due to clouds (or more broadly un- or under-resolved processes that must be parameterized) has led to enhanced interest in higher resolution global and regional models. In simple terms, the expectation is that significantly better simulations can be obtained by resolving cloud scale motions and relying less on cloud parameterizations. However, simulations capable of resolving cloud scale motions on global or large regional domains are computationally challenging. Simulations run on small domains (where fine grids can be applied) have demonstrated that horizontal grid spacings of less than 1 km are required to resolve many clouds. Likewise, vertical grids with grid point spacings less than 100 m are often needed in the boundary layer. From a climate modeling perspective, accurately capturing stratocumulus and the transition between stratocumulus and cumulus is critical because of the large role that these clouds play in the Earth radiation balance. One potential approach to increasing resolution with only modest increases in computational cost is to use an adaptive grid. In this approach, additional grid points are added to the (relatively coarse) model base grid only where needed, as determined by the model simulation itself. We have developed a Cloud Resolving Model (CRM) with an Adaptive Vertical Grid (AVG) and tested this model using case studies on small domains. These simulations show that the adaptive vertical grid is able to simulate clouds well when compared with simulations using much higher vertical resolution (and many more grid layers). We propose to test the adaptive vertical grid approach in global scale simulations by incorporating our AVG model into the Multiscale Modeling Framework (MMF) climate model. Output from MMF-AVG simulations will be rigorously compared with observations.

Development of a Prototype High Resolution Prediction System for Precipitation, Soil Moisture and Stream Flow over North America

S. Schubert, H. Wang, R. Koster, M. Suarez, and K. Mo

Abstract

Despite considerable advances in our understanding of drought mechanisms (role of SST, land atmosphere feedbacks, etc.), there has been little improvement in drought predictions on seasonal time scales. In fact, seasonal forecast information appears to provide little additional skill to hydrologic forecasts, beyond that obtained from the initial land conditions, though some improvement can be achieved by conditioning the forecasts on ENSO.

In this proposal we seek to improve hydrologic (precipitation, soil moisture, stream flow) prediction skill on subseasonal to seasonal time scales by developing and evaluating a prototype drought prediction system that takes advantage of a number of recent advances in our modeling and understanding of precipitation variability, as well as improvements in the soil moisture initial conditions. These advances consist of:

1) New understanding of the nature and role of stationary Rossby waves in controlling summertime middle latitude precipitation and surface temperature extremes on subseasonal time scales.
2) The development of ultra-high resolution (3.5 to 14km) versions of the NASA GEOS-5 non-hydrostatic global atmospheric model capable of resolving meso-scale and other high impact weather systems.
3) The availability of multiple land models to better span the uncertainties in the predictions tied to land model uncertainty.
4) Improved soil moisture initial conditions from the assimilation of AMSR-E and SMOS data.
5) A new set of forecasts/hindcasts using the latest versions of both the NOAA/CFS and NASA/GEOS-5 coupled models that have been initialized by the latest reanalysis products (CFSR and MERRA, respectively).

In order to leverage current capabilities, we divide the prediction approach into three tiers. Tier 1 consists of the new set of medium resolution (order 100km in the atmosphere) re-forecasts being produced by the atmosphere/ocean coupled NCEP/EMC and NASA/GMAO models. We will use the Tier 1 SST to drive our high-resolution (order 10km) Tier 2 AGCM predictions, with the atmosphere and land initialized from the MERRA reanalysis. We will also statistically downscale the Tier 1 atmosphere to 10km to provide a benchmark for the high-resolution AGCM predictions. The third tier consists of an ensemble of land model predictions, using atmospheric forcing (from the ensemble of tier 2 high resolution AGCM forecasts or the statistically downscaled Tier 1 predictions) and using multiple land models spun up with NLDAS forcing data. A subset of the Tier 3 ensemble members will be initialized with new soil moisture estimates obtained by the assimilation of AMSR-E and SMOS observations as they become available from the GMAO. Our deliverable is a prototype prediction system with a preliminary assessment of forecast skill. We will also work to extend the forecasts into near real time so that they could become a contribution to the NOAA/CPC drought briefings, providing additional guidance to drought outlook forecasters, as well as, contribute to the NIDIS goal of creating an "early warning system" for drought that provides accurate, timely, and integrated information.

Assimilating Soil Moisture and Snow Products for Improved Drought Monitoring with the North American Land Data Assimilation System (NLDAS)

PI: Christa D. Peters-Lidard
Co-PI: David Mocko (SAIC at NASA/GSFC)
Co-Investigators: Sujay Kumar (SAIC at NASA/GSFC),
Michael Ek (NOAA/NCEP/EMC), and
Youlong Xia and Jiarui Dong (IMSG at NOAA/NCEP/EMC)

Abstract

Background and Objectives

The North American Land Data Assimilation System (NLDAS) has a long successful history of producing surface meteorology and precipitation datasets used as forcing for land-surface models (LSMs) to produce soil moisture, snow cover, and runoff/streamflow products. These products have been used in numerous applications for researchers both within GAPP & CPPA as well as in other communities. Real-time NLDAS products are used for drought monitoring and as initial conditions for a drought forecast system. Currently, remotely-sensed estimates of land-surface states such as soil moisture and snowpack are not assimilated into NLDAS. Therefore, the primary objective of this proposal is to support the routine assimilation of remotely-sensed soil moisture, snow-covered area (SCA) and snow water-equivalent (SWE) in NLDAS. We believe that assimilating satellite products into NLDAS will not only produce improved soil moisture profiles and snowpack states to better represent evolving conditions, but will directly improve the monitoring of drought. To accomplish our objective, we propose to implement the current NLDAS system within the Land Information System (LIS) architecture, which will allow multiple LSMs to assimilate soil moisture, SCA and SWE. Additionally, we will implement the Catchment LSM (a successor to Mosaic) as well as the latest versions of Noah, SAC, and VIC.

Brief Summary of Work to be Completed

The proposed work will include the following Tasks: 1) Benchmark and extend NLDAS data production within the latest LIS architecture, including implementation of Catchment and the latest version of Noah, in addition to (re-)producing NLDAS outputs for the 1979-present retrospective period; 2) Assimilating AMSR-E soil moisture and SWE products and MODIS SCA products into the NLDAS system for better diagnosis of drought and improvement of initial land conditions in the NLDAS drought forecast system at NOAA/EMC; and 3) Evaluate NLDAS output products and drought monitoring skill both with and without assimilation.

Relevance to Program Announcement Research Area

The proposed work will be primarily relevant to the MAPP theme #2 – Develop an Integrated Drought Prediction Capability. The improvements to the NLDAS drought monitoring and data products for the drought forecast system will be made using multiple data sources and models to objectively evaluate model and data upgrades to soil moisture, hydrology, and vegetation. The capability to simultaneously execute multi-model ensembles and assimilate soil moisture and snow products using the existing capabilities of LIS at NCEP will represent a significant advance over the current state-of-the-art in drought assessment and prediction.

Project Title: DUAL ASSIMILATION OF MICROWAVE AND THERMAL-INFRARED SATELLITE OBSERVATIONS OF SOILMOISTURE INTO NLDAS FOR IMPROVED DROUGHTMONITORING

X. Zhan (*PI: NESDIS*), M.C. Anderson (*Co-PI: USDA-ARS*), C Hain (*NESDIS; IMSG*), M. Ek (*NCEP*),
M. Svoboda (*NDMC*), B. Wardlow (*NDMC*), W. Crow (*USDA-ARS*), J.R. Mecikalski (*U Alabama*), W.P.
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ABSTRACT

We propose to produce an operational data assimilation (DA) system for optimal integration of thermal infrared (TIR) and microwave (MV) soil moisture (SM) information and near real-time green vegetation fraction (GVF) into the Noah land-surface model component of the National Land Data Assimilation System (NLDAS). NLDAS produces hydrologic products (e.g. soil moisture, evapotranspiration, and runoff) used by NCEP for operational drought monitoring, but these products are sensitive to model input errors in soil texture (affecting infiltration rates) and prescribed precipitation rates. These types of model errors can be compensated for by periodically updating SM state variables in LSMs through assimilation of remotely sensed SM information. The work proposed here will build on a project currently funded under the Climate Test Bed Program entitled "A GOES Thermal-Based Drought Early Warning Index for NIDIS", which is developing an operational TIR SM index (Evaporative Stress Index; ESI) based on maps of the ratio of actual-to-potential ET (*fPET*) generated with the Atmosphere-Land Exchange Inverse (ALEXI) surface energy balance algorithm.

The assembled research team has demonstrated that diagnostic information about SM and evapotranspiration (ET) from MW and TIR remote sensing can significantly reduce SM drifts in LSMs such as Noah. The two retrievals have been shown to be quite complementary: TIR provides relatively high spatial resolution (down to 100 m) and low temporal resolution (due to cloud cover) retrievals over a wide range of GVF, while MW provides relatively low spatial (25 to 60 km) and high temporal resolution (can retrieve through cloud cover), but only over areas with low GVF. Furthermore, MW retrievals are sensitive to SM only in the first few centimeters of the soil profile, while in vegetated areas TIR provides information about SM conditions integrated over the full rootzone, reflected in the observed canopy temperature. The added value of TIR over MW alone is most significant in areas of moderate to dense vegetation cover where MW retrievals have very little sensitivity to SM at any depth.

Building on this work, the proposed study will develop an optimal strategy for assimilating TIR and MW SM signals into the Noah model over the NLDAS domain using the Land Information System (LIS) developed by NASA. Additionally, near real-time green vegetation fraction (GVF) data products generated in NESDIS will be ingested, replacing climatological fields currently used in NLDAS, which are not always representative of actual conditions on the ground, especially in areas suffering from drought. We propose to use relative TIR / MW skill maps developed by Co-I Hain to spatiotemporally modify error characteristics needed by the EnKF as a function of GVF. Assimilation results will be validated in comparison with in-situ SM observations and using a data denial validation methodology. Outputs from the operational DA system will include near real-time (updated each night) maps of surface and root-zone SM, ET and runoff. Anomalies computed from these improved hydrologic products will be compared to ALEXI ESI and standard drought metrics, including the operational NLDAS output. Output will be distributed in real-time to NCEP-CPC for use in the North America Drought Briefing and to the National Drought Mitigation Center in support of the U.S. Drought Monitor.

Title: Improving seasonal drought predictions in the western USA: Developing and evaluating an ensemble snow modeling framework in the Community Hydrologic Prediction System (CHPS).

Institutions: National Center for Atmospheric Research, University of Colorado, Colorado Basin River Forecast Center.
Investigators: Martyn Clark, Andrew Slater, Andrew Wood, Thomas Hopson, Ethan Guttmann

The predictability of hydrologic drought depends in large part on land surface memory; in particular, the capability to simulate the seasonal evolution of snow and soil moisture. The skill of seasonal drought predictions in the western USA is therefore intimately linked to the validity of hydrologic and land-surface models that are used to produce the predictions. The goal of this proposal is to improve predictions of hydrologic drought in the western USA; specifically to both improve model representations of snow processes and quantify uncertainty in snow simulations. We focus on snow because a large amount of predictability in seasonal streamflow in the western USA is derived from knowledge of the accumulated snowpack.

Our proposed research has four elements:

1) Develop and test a framework for improving model selection/specification in hydrologic modeling. This involves summarizing the different decisions regarding process selection and representation, and integrating multiple representations of all important snow processes into a common modeling framework.
2) Apply this framework to assess appropriateness of current modeling approaches, and provide recommendations on methods to improve existing snow models. Testing model hypotheses requires data that is not routinely collected in standard observing networks, and, as such, we propose to collate data from existing experimental studies. Using these data we will identify appropriate quantitative metrics to evaluate model decisions and identify a range (ensemble) of scientifically defensible model representations.
3) Quantify uncertainty in model simulations by allowing for ambiguity in the representation of different processes. Explicitly formulating the multiple working hypotheses at the level of model sub-components (rather than entire models) can mean that inter-model differences in our system provide a superior estimate of structural uncertainty than in multi-model systems that include a small number of individual models of varying complexity.
4) Incorporate these modeling approaches in the CHPS system to evaluate the value of physically realistic snow models for seasonal drought predictions. Use of flexible modeling approaches and multi-model approaches provide a thorough test of CHPS as an integrative modeling system.

This proposed project directly addresses the desired elements of the FY2011 call, specifically by (i) providing a capability to link multiple model components; and (ii) evaluating uncertainties based on model formulation.

Integrating Data Assimilation and Multi-modeling Within CHPS for Improved Seasonal Drought Prediction

(PI) Hamid Moradkhani, Portland State University
(Collaborator) Andrew Wood, Development and Operations Hydrologist, CBRFC
(Collaborator) Donald Laurine, Development and Operations Hydrologist, NWRFC

Abstract

MAPP supports developing an Integrated Drought Prediction Capability that incorporates research advances into operational intraseasonal to interannual climate and hydrologic prediction by means of multiple data sources and models, land-surface and hydrologic modeling, and data assimilation. Improved long-range hydrologic drought forecasts can help to mitigate drought impacts-they provide guidance to agencies responsible for water allocation, water conservation, and the mitigation of other adverse impacts such as wild land fires. With respect to drought characterization and prediction, the U.S. Drought Monitor (DM) and the NOAA Climate Prediction Center's (CPC) US Drought Outlook (DO), are the primary operational tools available to water managers charged with dealing with drought contingencies. However, both the DM and DO depend on a range of tools from simple statistical indices to water balance models driven by statistical forecasts.

Remote sensing-based real-time snow extent fields can, in some regions, help characterize one of the key components used to define drought, which is critically important for identifying conditions that could flicker seasonal droughts. In operational forecasting, however, consideration has been given to methodologies that include coupling both multiple climate and multiple hydrological models, increasing the pool of streamflow forecast ensemble members and accounting for cumulative sources of uncertainty. Here, we propose a three-year collaborative research project that will quantify and reduce the major uncertainties involved in drought forecasting by implementing state of the art of land data assimilation methods and Bayesian multi-model combination in the context of seasonal hydrologic forecast system. We will focus in particular on those observed variables that have been shown to have the greatest potential for improving hydrological forecasts in the western U.S., specifically in situ observations of Snow Water Equivalent (SWE); remotely sensed observations of Snow Cover Extent (SCE) from MODIS and streamflow from USGS gauges. We will also investigate, on a more local basis, the potential for assimilation of in situ soil moisture from the USDA SCAN network given the difficulty and inaccuracy in using remotely sensed soil moisture fields for the western US.

The system we propose will use Community Hydrologic Prediction System (CHPS) as the framework to incorporate hydrologic and land surface models developed over the last three decades with methods of improving hydrologic initial conditions (i.e., land data assimilation) and its integration with Ensemble Streamflow Prediction (ESP) which are the key aspects of the proposed research. This proposal, which is a collaboration of Hamid Moradkhani at Portland State University (PSU) with Andy Wood at CBRFC and Donald Laurine at NWRFC responds to the second area solicited on the MAPP Information Sheet "*Develop an Integrated Drought Prediction Capability by incorporating research advances in climate prediction, land-surface and hydrologic modeling, and data assimilation*". It will integrate past CPPA-funded research by the PI and others in the development and application of drought forecasting. In particular, project benefits from the participation of development and operation hydrologists at two RFCs to ensure the transition of research to operation in the western US with the transformable potential to other regions. Summary of work to be completed include the following tasks: **1)** Establish domains for retrospective analysis. To limit the data

volumes involved in proposed analyses, sub-basins or sub-regions of the domains will be identified. Criteria to be considered will include the availability of the observed verification datasets and the presence of drought; **2)** Gather and pre-process in situ and historical remote sensing datasets. For the domains identified in Task 1, the necessary remote sensing products will be processed into convenient form for analysis and archived for further analysis; **3)** Set up each hydrologic model for the study domains and implement the advanced model calibration to ensure the suitability and effectiveness of each model for further analysis; **4)** Implement ensemble data assimilation to quantify the uncertainties associated with the land surface initial condition required for 1-12 months ensemble streamflow prediction; **5)** Develop the multi-model ensemble combination of hydrologic forecasting for both soil moisture and streamflow; **6)** Conduct retrospective assessment on the hydrologic/drought prediction skills using single and multi-modeling as developed in Tasks 4 and 5; **7)** Incorporate the framework within the newly developed operational Community Hydrologic Prediction system (CHPS).

Proposal Title: Assessing the quality of synoptic scale variability derived from the Twentieth Century Reanalysis Project

Institution: The Research Foundation of SUNY, Stony Brook University
Investigator: Edmund Kar-Man Chang

Introduction of the problem and rationale:

Faced with the prospect of climate change due to global warming, detailed projections of how regional climate may change are needed for policy makers to assess different strategies for adaptation and mitigation. Currently, regional aspects of climate change still faces tremendous uncertainties, both in terms of the ability of global climate models to adequately simulate regional climate, as well as the need of a physically and dynamically consistent long term dataset to assess regional climate variability and to validate climate model simulations. Previous studies, including those by the PI, have shown that previous reanalysis datasets have spurious trends in the statistics of synoptic scale weather systems due to improvements in the observation system over time, and thus are not suitable for the characterization of decadal variability and trends of these systems. The new dataset from the 20th Century Reanalysis Project (20CR) is expected to suffer from less of such time dependent biases because it uses an advanced data assimilation system to assimilate only a single type of observations (surface pressure observations) that had undergone the least changes over time. However, the frequency and quality of observations ingested into 20CR have still undergone significant temporal variations over the 20th Century, thus the quality and consistency of the statistics of synoptic scale weather systems derived from the 20CR still needs to be assessed.

Brief summary of work to be completed:

The statistics of synoptic scale weather systems, in terms of variance/covariance statistics of mean sea level pressure and other quantities such as geopotential height, meridional wind, and temperature, will be derived from 20CR and compared directly to similar statistics derived from surface ship and upper-air radiosonde observations to assess the quality and consistency of such statistics derived from the 20CR. Since variability of synoptic scale weather systems and mean flow variability are closely tied to each other, statistical models will be used to assess whether the relationships between synoptic scale and mean flow variabilities are consistent throughout the 20th Century. Feature tracking statistics (including statistics of surface and upper level cyclones) will be derived from 20CR and compared to those derived from other reanalysis products to assess how changes in the observing system might have affected cyclone statistics. The completion of this project will result in better understanding of past variability of synoptic scale weather systems, and provide climate scientists with an assessment of the period over which synoptic scale variability derived from 20CR is consistent, and climate modelers with a validation of the dataset that they can use to assess climate model simulations, thereby resulting in better understanding of the ability of climate models to simulate and project changes in regional climate, resulting in improved assessment of the projected regional climate change by climate models.

Title: Regional and global evaluation of the CFS-R and 20th Century Reanalysis for the terrestrial water cycle.
PIs and Institutions: Eric F Wood, Princeton University

Reanalysis data sets have become an important and integral resource for studying the water cycle at regional to global scales. Since the first NCEP/NCAR reanalysis data sets were released in the mid-1990s, their use has been cited over 6,000 times. Reanalysis data sets offer homogeneous, gridded data products that have found wide application as input forcing data for off-line hydroclimate models and regional coupled models, for carrying diagnostic analysis for climate studies and for bias correcting and downscaling coarse-scale climate models. Thus it is critical that CFS-R and 20CR be evaluated both in absolute terms against observational data on specific variables and for consistency with previous reanalysis products. Very recently, the global high resolution Climate Forecast System Reanalysis (CFS-R) has been completed at NCEP/NWS for 1979-2009, as well as the 20th Century Reanalysis (20CR) at ESRL.

It is proposed to evaluate CFS-R and 20CR data products for the terrestrial water cycle over 32 global river basins, and for selected variables globally. The project will focus on three important evaluations: The first will be traditional error and bias analysis using regional and global data sets developed, compiled and analyzed by the PI over the last decade. Variables will include precipitation, temperature, river discharge, changes in terrestrial water storage, surface radiation and heat flux, and atmospheric profiles of temperature and humidity. For all variables, the data sets are already archived with the PI and have been used for water cycle studies. In most cases multiple data sets are available for each variable, permitting uncertainty assessment for CFS-R and 20CR data products. The second tier evaluation focuses on the consistency between CFS-R (or 20CR) and recently completed reanalysis, which include ERA-40, ERA-interim, MERRA and NARR. It is important for the community have an assessment of CFS-R and 20CR data products relative to currently available reanalysis products. The third tier evaluation focuses on higher-level products important to hydroclimate analysis and modeling. Evaluations will include such variables as the trends and variability in CFS-R and 20CR time series, rain-day frequency statistics (critical to hydrologic modeling and applications), reproduction of large-scale climate events (like drought) and the frequency of heavy precipitation, and reproduction of observed teleconnections such as ENSO and western U.S. precipitation.

Carrying out the proposed comprehensive CFS-R and 20CR evaluation within the one year project is only feasible due to our ongoing and previous work in evaluating/validating currently available reanalysis products (e.g. ERA40, ERA-Interim, MERRA, NARR), with in-situ (e.g. gauge or radar precipitation, tower-based ET, station-based radiation), remote sensing retrievals (e.g. MW/IR derived precipitation, remotely sensed ET, GRACE derived terrestrial water storage and AIRS derived atmospheric water vapor and temperature), and land surface modeling (VIC) surface water and energy cycle variables. Our current research on estimating the terrestrial water cycle against *multiple* observational and modeling products will allow an evaluation of CFS-R and 20CR products in an important, broader context.

Proposal Title: Evaluating Dynamical States, Radiation Budgets, and Cloud Properties in the NCEP CFS-R and ECMWF ERA Interim Output

Institution: Joint Institute for the Study of the Atmosphere and Ocean, University of Washington
Investigators: Thomas P. Ackerman and Laura M. Hinkelman

We propose to evaluate the dynamical states, radiation budget, and cloud properties of the NCEP Climate Forecast System Reanalysis (CFS-R) and the ECMWF interim reanalysis (ERA-I). (As time permits, we will also evaluate the NASA GMAO MERRA.) We will begin by comparing global TOA and surface radiation budgets for both shortwave and longwave radiation from the reanalysis output with data from CERES (at TOA) and the NASA/GEWEX Surface Radiation Budget (SRB) project on monthly to interannual timescales. We will then perform a cluster classification of atmospheric states for both CFS-R and ERA-I at the DOE SGP site and the DOE TWP site in Darwin, Australia. We will then compare (a) state classification results and probability of occurrence statistics from the two reanalyses, (b) cloud occurrence profiles for each reanalysis state with each other and observed cloud profiles, and (c) probability distributions of reanalysis physical variables (such as precipitation, cloud liquid water path, and cloud radiative effect) by state with observations. We intend to link simulator codes for MISR, MODIS, and ISCCP to the reanalysis output streams to produce simulated cloud top heights (or pressures) and optical depths. Joint histograms from the reanalyses will then be compared with similar histograms from observations on a regional basis. Our final product will be a summary statement of the accuracy of the reanalysis radiation budgets, their relative similarity of dynamical states, the accuracy of cloud profiles and other geophysical variables associate with these states, and the influence of cloud errors on radiative budget errors.

Using Historical Surface Data to Verify the Twentieth Century Reanalysis for Oceanographic Applications

University of Maryland, College Park
James A. Carton and Semyon A. Grodsky

The Twentieth Century (20CRv.2) Reanalysis Project of *Compo et al. (2010*) more than doubles the time span covered by atmospheric reanalyses, and in addition uses an assimilation methodology that provides information about the accuracy of the reanalysis. Thus the 20CRv.2 potentially offers wonderful advantages for use in multi-decadal ocean circulation and climate studies. This proposal will help fulfill that promise by supporting exploration of the surface winds from the 20CRv.2 in two stages. The first stage will involve comparison of the 20CRv.2 and other multi-decadal reanalyses to wind observations such as those contained in ICOADS (which were not used in the 20CRv.2 assimilation) to estimate accuracy various space and timescales and to detect the presence of time-dependent biases. The second stage will involve examination of output from a simulation of an ocean general circulation model driven by reanalysis winds in comparison with the historical hydrographic record.

Evaluation of Reanalysis Products in the Arctic

PI: Ronald W. Lindsay, Senior Physicist
Polar Science Center, Applied Physics Laboratory
University of Washington, Seattle WA

How well can we estimate the state of the atmosphere and the rate it is changing in the polar regions in retrospective analyses? In the data sparse Arctic, atmospheric analyses are poorly constrained by observations and are strongly influenced by model parameterizations. There are currently seven different sets of global reanalysis products that are current or near current in temporal coverage: NCEP-1, NCEP-2, CFSR, 20CR, MERRA, ERA-Interim, and JRA-25 (definitions follow).

Retrospective analyses have been a critical tool in studying weather and climate variability for the last 15 years. Reanalyses blend the continuity and breadth of output data from a numerical model with the constraint of vast quantities of surface, radiosonde, and satellite observational data. The result is a long-term continuous and spatially complete data record. Reanalysis products are used in many different applications including evaluation of atmospheric circulation patterns and processes, change detection, the forcing of ice–ocean models, regional atmospheric models, land models, or air chemistry models, and for establishing the initial conditions for forecast models. Better understanding the strengths and weaknesses of these products will improve our ability to evaluate the long-term trends in the rapidly changing Arctic environment and may also improve our ability to make seasonal projections of sea ice and weather conditions in the Arctic.

In this focused study we will compare the monthly mean estimates of the surface and tropospheric air temperature, the surface pressure and winds, the total precipitation, and the surface and top-of-the-atmosphere radiative fluxes in a three-tiered set of analyses. The first-order comparisons will be made to independent point observations from a selected set of land stations and drifting ice stations. The second-order comparisons will be made of the statistical properties (mean, standard deviation, and extremes) of the fields from each of the reanalyses. Finally, the third-order comparisons will be made of the 30-year trends in the fields of each of the reanalyses. While this is an ambitious project to accomplish in just one year, we plan to use the economies of scale to perform the identical analysis procedures on all six of the reanalysis products.

The ultimate goal is to better understand the strengths and weaknesses of these products in a data-sparse region where the reanalysis models may differ the most. Better understanding of these products may improve the ability for NOAA to make seasonal projections of sea ice and weather conditions in the Arctic.

Comparison of Structure and Evolution Characteristics of Boreal Summer and Winter Intraseasonal Oscillations Derived from Reanalysis Products and Satellite observations

Principal Investigator**: Dr. Tim Li**
Department of Meteorology and IPRC, SOEST
University of Hawaii at Manoa
Co-PI**: Dr. Xianan Jiang**
Joint Inst. for Reg. Earth System Science & Engineering
University of California

PROJECT SUMMARY

The proposed project is to evaluate the performance of various latest reanalysis products in capturing the MJO 3D structures, particularly its vertical heating and humidity profiles, and MJO multi-scale characteristics and initiation processes. The reanalysis products to be evaluated include the NCEP Climate Forecast System (CFS) Reanalysis, the ESRL 100-year Historical Reanalysis, NASA MERRA, ERA-interim, and JMA reanalysis. Available observations from recently available satellite products and planned field campaigns will be used to validate the reanalysis products.

Firstly, we will diagnose and compare the 3D dynamic and thermodynamic structures at various phases of the MJO. Because of distinctive seasonal evolution characteristics, we will separate the boreal winter (November-April) and summer (May-October) seasons. We will examine the horizontal and vertical profiles of specific humidity and its relationships with MJO convection, vorticity, divergence, vertical motion, surface fluxes, SST, CAPE, and other dynamic and thermodynamic variables. A key variable to examine is the heating field. Daily 3D fields of apparent heating (Q1; Yanai et al. 1973) derived from the above reanalysis datasets will be compared with each other, and validated against TRMM estimate based on the "Trained" Radiometer Heating (TRAIN), Convective-Stratiform Heating (CSH), and Spectral Latent Heating (SLH) algorithms. We will evaluate the evolution of the heating profiles associated with shallow (congestus) convection, deep convection and stratiform clouds.

Secondly, we will evaluate and compare the multi-scale characteristics of the MJO in both the boreal winter and summer seasons. A focus will be on the structure and evolution of higher-frequency perturbations and their MJO-phase-dependent feature. A spatial-temporal wavelet transform method will be applied to separate higher frequency modes. The possible upscale feedback of higher-frequency perturbations to MJO will be examined with a new diagnostic strategy that separates the eddy interaction with ISO and slowly varying background mean flows. In addition, we will reveal the common features associated with the MJO initiation in the western equatorial Indian Ocean based on the diagnosis of the reanalysis products.

Title: Evaluate Recently Developed Reanalysis Projects
Institution: University of Miami Rosenstiel School of Marine and Atmospheric Science
Principal Investigator: Chidong Zhang, Ph.D.

This proposal is submitted to NOAA Climate Project Office Modeling, Analysis, Prediction and Projection (MAPP) Program in Response to Funding Opportunity for FY2011. In this project, we will make efforts to contribute to the MAPP FY2011 theme of **Evaluate Recently Developed Reanalysis Projects**. The overall goal of this proposed project is to provide quantitative information that may guide us to properly use diabatic heating profiles from the recent reanalysis products: MERRA, CFS-R, and ERA-Interim. We propose to (i) quantify similarities and differences between Q1 (total diabatic heating estimated as a residual of heat budget) and QT (direct output of total diabatic heating) from the reanalyses, (ii) compare Q1 (and QT if they are equivalent) from the reanalyses to Q1 estimated using sounding data from selected field campaign, and (iii) define our current knowledge of diabatic heating profiles and its uncertainties by quantifying the agreement and discrepancies between diabatic heating profiles from the reanalyses.

The research will be conducted at CIMAS/RSMAS, University of Miami, addressing CIMAS Theme 1: Climate Variability (Task 3).

Climatology and variability of tropical rainfall in the 20th Century Reanalysis.

PIs: Michela Biasutti and Mingfang Ting
Lamont-Doherty Earth Observatory, the Earth Institute at Columbia University

Summary

We propose to validate the climatology and variability of tropical rainfall in the 20th Century reanalysis, version 2 (20CRv2, Compo et al., 2010). To do so we will compare the reanalyzed precipitation to global satellite-based records for the most recent past, to several land-only datasets that go back to the beginning of the century, and to statistical reconstructions of marine precipitation (Smith et al., 2008, 2010).

Our first task will be to document rainfall biases both in terms of their monthly and seasonal patterns and in terms of the characteristics of daily precipitation. We will try to better understand the source of these biases by replicating the work of Biasutti et al. (2006), which diagnosed the strength of dynamical (i.e. convergence) and thermodynamical (i.e stability) control on rainfall in several GCMs and reanalyses.

Second, we will contrast the time-series of regional rainfall in the reanalysis and in observations. Some preliminary analysis for the African Sahel suggests that the 20CRv2 precipitation monthly anomalies depend strongly on the density of the observational records of surface pressure that are assimilated: when the synoptic spread in surface pressure is relatively low, the ensemble-mean monthly rainfall anomalies track observations very well, but when the spread is large, the correlation with observations drops below what we would expect from AMIP simulations.

Given the limited skill of the 20CRv2 reanalysis in reproducing historical variations of precipitation in data-sparse regions and periods, it is desirable to understand whether a MOS correction could be applied to the reanalyzed fields to create a trustworthy, complete record of rainfall. The idea behind a MOS correction is that models that do a poor job of simulating rainfall might still have skill at simulating the large-scale circulation associated with an observed rainfall anomalies.

If the reanalyzed time series of the tropical circulation is found to be accurate, and the relationship between circulation and rainfall is found to be stationary, then it would be appropriate to create a MOScorrected record of rainfall. Although the short duration of this project prevents us from producing such a record, we propose to test whether it would be possible. To do so, we will both validate the historical variations of key circulation indices (for example, the Southern Oscillation Index and the monsoon indices), and test the fidelity and stationarity of the relationship between regional rainfall anomalies and circulation anomalies.

**Title: Implementation of the Noah land surface model upgrades in the NCEP Climate
Forecast System**
Institution: EMC/NCEP/NOAA
Co-Principal Investigators: Michael Ek and Jesse Meng
EMC/NCEP/NOAA
Co-Investigator: Rongqian Yang, EMC/NCEP/NOAA

The objective of this proposal is to transition and infuse the recent developments of the Noah land surface model into NCEP operation to improve the skill and reliability of NCEP seasonal climate predictions of precipitation, temperature and land-surface hydrological variables, such as soil moisture, runoff and snowpack. The improvement in prediction skill is to be accomplished by means of improved representation of land surface processes and land-atmosphere interactions in the NCEP operational global and regional climate prediction systems, including their companion land data assimilation systems.

The scientific basis for this objective is that climate predictability on intraseasonal to interannual time scales is largely determined by slow variations of the ocean and land surface states. This proposal aims to improve the understanding and modeling of land surface processes through a focus on better understanding of land-atmosphere interactions and related hydrometeorological physics. Upgrades in the Noah land surface model, coupled to the NCEP Climate Forecast System, will be the parameterizations for cold season snow processes, surface thermal roughness, groundwater and runoff, vegetation canopy layer, and dynamic vegetation.

To achieve the above objective, this proposal will establish explicit interfaces between internal NCEP operational climate prediction model developers and external academic researchers, in particular those who received funding from the NOAA Climate Program Office, to facilitate the transition from research to operation. Specifically, to transition those tested, proven, CPO funded research projects to NOAA operations.

Title: Enhancement of high resolution hydrological modeling on the CONUS HRAP grid using operational NOAA NCEP and NOAA OHD models
Institutions: OHD/NWS/NOAA, EMC/NCEP/NOAA, and CPC/NCEP/NOAA
Principal Investigators: Brian A. Cosgrove (OHD) and Jiarui Dong (EMC)
Co-Investigators: Michael Ek (EMC) and Kingtse Mo (CPC)

This proposal centers on supporting NOAA/NCEP's, NOAA/OHD's, and NOAA/CPC's operational hydrological and land surface modeling missions, as well as furthering their support of the NOAA Hydrology Test Bed, the NOAA Climate Test Bed, and the National Integrated Drought Information System *(*NIDIS). New capabilities resulting from this joint NOAA NCEP/OHD/CPC effort will allow for the execution of *enhanced* Noah and Sacramento Heat Transfer (SAC-HT) models on the 4km HRAP grid over the Continental United States (CONUS). Enhancements will impact all stages of modeling operations and will include improved downscaled forcing data, spin-up strategies, data assimilator modules, model physics, and model validation procedures, and will enable national runoff routing of both Noah and SAC-HT output. Additionally, for the National Integrated Drought Information System, this research will yield 31-year high-resolution model climatologies in support of the monitoring and prediction of drought and other hydrologic variables.

The proposed work will leverage forcing data from the North American Land Data Assimilation System which features a 1/8th degree spatial resolution, and topography that differs significantly from that which will be used in the proposed 4km modeling effort. As such, we will apply a novel lapse-rate-based elevation adjustment scheme to downscale the NLDAS forcing to the 4km HRAP grid. As the lapse rate has been found to vary significantly in space and time, we further propose to find a proxy to quantitatively predict the variations of the lapse rate.

Accurate initialization of land surface and hydrological models is critical for correct hydrological predictions, because the process of a model adjusting to its forcing can severely bias land surface simulations. We propose to make a thorough investigation and develop a technique to generate optimal initial conditions for the 31-year (1979-2009) 4km Noah and SAC-HT retrospective simulations and to provide guidance for realtime simulations.

Complementing the forcing and spin-up work described above will be improvements to the models' data assimilation modules. We will design and test several innovative data assimilation techniques for ingesting the MODIS snow cover area observations into the SAC-HT/Snow17 and Noah models. The proposed algorithm is superior to existing methods in that it (i) uses the traditional bisection method to study the inverse of the usual problem by finding the SWE which optimally matches the MODIS-derived SCF observations, (ii) incorporates improved error estimates for snow observations, and (iii) dynamically propagates estimated model error for snow states within a Kalman filtering framework. Results will be compared with existing analysis products and validated using ground based measurements.

The final aspect of this research centers on the CONUS-wide testing in NASA's Land Information System (LIS) of SAC-HT, Snow17, and Noah model physics and parameter improvements. Two recent improvements in SAC-HT will be extensively evaluated: 1) Incorporation of Noah's evapotranspiration physics, and 2) Improvement of sub-surface runoff modeling. OHD's Snow 17 model will benefit through imtegratopm of a new dynamic parameterization scheme which will negate the need to manually derive many of the model's parameters. Similarly, a suite of Noah LSM improvements will be integrated and assessed including a new snow albedo scheme, a canopy conductance formulation, a surface flux formulation. Both models will benefit from incorporation into LIS of OHD's streamflow routing module. Together, the proposed improvements will greatly enhance the operational and research modeling capabilities of NOAA/NCEP and NOAA/OHD, as well as the numerous research groups who make use of these publically available models.

Title: Improving land evaporative processes and land-atmosphere interactions in the NCEP Global Forecast System (GFS) and Climate Forecast System (CFS).

PI and institution: Eric Wood, Princeton University.
Co-PI and institution: Michael Ek, NCEP EMC.
Co-I and institution: Justin Sheffield, Princeton University.

Introduction to the Problem: Surface evapotranspiration is often considered *the* climate linchpin variable because it forms the bridge across the water, energy and carbon cycles. Evaporation plays a central role in coupling the land and atmosphere, and operates over fast (diurnal) and slow (seasonal) time scales. Evaporation from water bodies, vegetation intercepted precipitation or soil surfaces, and transpiration from plants combine to return available water at the surface layer back to the bulk atmosphere in a process referred to as evapotranspiration (ET). Controls on terrestrial ET are particularly complicated and are constrained by the surface radiation, the state of the vegetation-soil system, or the atmospheric boundary layer and its surface meteorology. Accurately modeling terrestrial evapotranspiration processes, including land-atmospheric coupling and recycling, is fundamental to climate predictions and projections. Errors in ET directly cascade through the water, energy and carbon cycles at all time scales. The goal of the proposed project is to analyze, evaluate and improve land evaporative processes in the Noah land surface component of the NOAA National Centers for
Environmental Prediction (NCEP) Global Forecast System (GFS) and Climate Forecast System (CFS) that will directly lead to improved climate predictions in these and other NCEP models. The focus of the project is on warm season terrestrial evaporative processes that include free evaporation from water bodies and canopy intercepted precipitation, evaporation of soil water, and transpiration by vegetation.
All of the above processes are parameterized separately in the GFS/CFS but collectively considered as ET or, in its energy form, latent heat flux.
Rationale: Over the last ten years a significant body of research has shown that little agreement exists among climate models in their simulations of land evaporative fluxes, even for current 20th C climate.
Analyses of land-atmospheric coupling, as measured by metrics like the inferred lifting condensation level (LCL), show wide disparity from weak to extremely tight coupling. Careful assessments of the parameterizations that control vegetation response to soil drying show that values being used are inconsistent with vegetation characteristics and provide unrealistic responses. Collectively, analyses to date show that climate models do a poor job in representing land evaporative processes. Given the central role of evaporative processes in the climate system, resolving these inadequacies is extremely relevant to improvements in climate models. Recent years have seen advancements in the analysis of evaporative processes (especially in the understanding of how surface heat fluxes couple to the boundary layer), in measuring land evaporative fluxes through eddy correlation techniques from towers under the AmeriFlux (and globally the FluxNet) initiatives, and in measuring atmospheric and surface properties from spaceborne sensors. These and other advances will be used to analyze and evaluate the land evaporative processes in the NCEP climate models and to develop improved parameterizations.
Summary of work to be completed: *1. Data set selection and compilation* of the in-situ flux tower and remote sensing data sets for long-term flux tower sites that represent a range of climates and vegetation types for the modeling and diagnostic analyses. *2: Generation of off-line and coupled climate model runs* using the Noah off-line version of the NCEP land surface scheme using forcing data for the tower sites and extending existing GLACE-2 hindcasts to nearer realtime. *3. Diagnostic analyses of off-line and coupled runs* of evaporative processes using metrics of land contribution to climate prediction skill and land-atmosphere coupling. *4. Model experiments for assessing process deficiencies*. *5. Developing and testing new ET parameterizations* including calibration of existing parameterizations, inclusion of canopy physiology models, sub-

grid scale soil moisture variations, prognostic canopy airspace parameterizations, and improved canopy interception.

NOAA Climate Test Bed (CTB)
National Multi-Model Ensemble (NMME) Prediction System
Phase-1 NMME Implementation Plan

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The recent US National Academies "Assessment of Intraseasonal to Interannual Climate Prediction and Predictability" (NRC 20101) was unequivocal in recommending the need for the development of a US NMME operational predictive capability. Indeed, the national effort is required to meet the specific tailored regional prediction and decision support needs of the emerging National Climate Service. The challenge is to meet this national need without diluting existing model development activities at the major centers and ensure that the forecast products continue to improve and be of societal value.

There is little doubt that US participation in EUROSIP is beneficial to both the US and European forecasting communities and users of the forecasts. However, as a US National Climate Service emerges and as the possible National Center for Predictions and Projections (NCPP) develops, the need for a NMME system becomes paramount for supporting continued research on MME based prediction that can transition to operations. For example, a NMME system facilitates modifications (e.g., extending the forecast to longer time-scales) to the forecast strategy, allows for better coordination of the forecast runs compared to EUROSIP (e.g., hindcast period, forecast scheduling etc.) and allows free exchange of data beyond what is supported by EUROSIP. Also, by testing various national models on weather and seasonal time-scales, the NMME system will accelerate the feedback and interaction between US ISI prediction research, US model development and the decision science that the forecast products support. For instance, the prediction systems can potentially be used to evaluate and design longterm climate observing systems, because US scientists will have open access to the prediction systems (i.e. data, data assimilation and forecast models). Our national interests require that we (1) run these ISI prediction systems operationally in the US, (2) retain the flexibility to modify the prediction systems and how they are used based on emerging national needs, and (3) ensure that there is a robust communication and collaboration network open among operational ISI forecasting, research and model development.